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SOME REMARKS ON THE CONTROL AND STABILITY CHARACTERISTICS OF THE FLYING PLATFORM

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SOME REMARKS ON THE CONTROL AND STABILITY
CHARACTERISTICS OF THE FLYING PLATFORM
(LOW SPEED FLIGHT REGIME)

April 26, 1956

Report No. 111

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No. of pages 9

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ADVANCED RESEARCH DIVISION
OF
HILLER HELICOPTERS

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I. INTRODUCTION

The fact that a properly designed platform is relatively easy to fly brings up the following questions:

a) What are the basic flight characteristics of such an airborne vehicle?

b) How can these control and stability characteristics be modified, if so desired?

c) What are the limitations?

One of the unique features of the platform is that conventional longitudinal and lateral control is eliminated and replaced by "kinesthetic" control. This means that the pilot applies control by shifting his weight in the direction he wishes to go. But kinesthetic control means something more than just that, it includes the utilization of the same instinctive reactions a person uses to stand and walk. The latter has the effect that the pilot acts unconsciously as an autopilot and by that automatically counteracts any disturbances which may occur.

In the present report, however, this instinctive human behavior has been neglected. For simplicity, it is assumed that the pilot is rigidly connected with the aircraft and shifts his weight only in the very moment a change in the direction of flight is initiated. In conventional aircraft terminology, we consider "stick fixed" conditions.

If the pilot tilts his body through an angle β (positive forward) about his ankle, he applies a pitching moment

$$M = M_\beta \beta \tag{1}$$

where the quantity

$$M_\beta = \frac{\partial M}{\partial \beta} = - W_p h \tag{2}$$

In these equations

W_p = pilot weight

h = distance between pilot's c.g. and his ankle

For an average pilot with M_β = - 600 lb ft/rad. and a maximum tilt angle $\beta = 15^\circ$ it follows that the maximum control moment available amounts to approximately

$$(M_{control})_{max} = \pm 155 \text{ lb ft} \tag{3}$$

The platform has, therefore, to be laid out in such a way that the control moment required for any flight condition is smaller than the maximum value listed above. It may be worthwhile to mention that the control effect is different from that of a conventional rotary wing aircraft. If, for example, the pilot of a helicopter applies longitudinal control he tilts the thrust vector of the rotor and by that immediately generates both a horizontal force and a pitching moment. In the case of the platform a tilt of the pilot only produces a pitching moment. A horizontal force occurs <u>after</u> the platform has been tilted due to the control moment applied. The initial angular acceleration of the platform can be written as

$$\ddot{\alpha} = - \frac{\beta M_\beta}{I} \text{ rad/sec}^2 \tag{4}$$

where the quantity I denotes the total pitching moment of inertia about the instantaneous c.g. For the present platform $M_\beta/I \cong 6\ s^{-2}$ which means that one second after an abrupt pilot tilt of one degree the platform has changed its attitude approximately three degrees.

II. STABILITY DERIVATIVES

The foregoing remarks already indicate that the flight characteristics of the platform are primarily controlled by the equilibrium of the pitching (or rolling) moments, i.e., by the moment stability derivatives. As in the case of the fixed wing aircraft, the following derivatives come into the picture:

1) Static Stability

Unfortunately, the platform like any unstabilized helicopter or other vertical rising vehicle is neutrally stable with angle of attack in hovering or near hovering flight. Unless automatic control is applied, nothing can be done about it. In the case of the platform, however, the instinctive reaction of the human pilot acts to a certain extent as a device resulting in stability with angle of attack. This effect is the subject of a separate study and, as mentioned previously, will be disregarded in the present paper.

2) Damping in Pitch or Roll

The damping in pitch or roll depends on the dimensions and RPM of the shrouded propellers and, to a minor degree, on the vertical c.g. location of the platform. As the layout of the propellers is controlled by performance considerations and, as will be seen later, the vertical c.g. range is limited by the flight characteristics, the damping in pitch and roll have to be considered as quantities which are more or less fixed.

3) Stability with Speed

Fortunately, the speed stability can be varied over a wide range from positive values to zero and even to negative values. It is, in fact, practically the only derivative which enables the designer to affect the flight characteristics appreciably and is, therefore, one of the major design parameters.

It should be clearly understood that the possibility of reducing the speed stability is a very desirable feature of the platform which distinguishes it from the helicopter. The helicopter has generally too much speed stability which results in dynamic instability.

III. EFFECT OF C.G. LOCATION ON SPEED STABILITY

Truck tests conducted on the platform show that an increase u in the horizontal velocity results in a horizontal force

$$H = H_u u \tag{5}$$

and a pitching moment

$$M_o = M_{o_u} u \tag{6}$$

See Figure 1. The resulting moment about the c.g. is

$$M = M_o - eH \tag{7}$$

where e denotes the vertical distance between the c.g. and the force H. It can easily be seen that the speed stability

$$M_u = M_{o_u} - eH_u \tag{8}$$

decreases with increasing distance e and that for

$$e = \frac{M_{o_u}}{H_u} \tag{9}$$

zero speed stability is obtained. See Figure 2. The curve of Figure 2 demonstrates that by proper vertical c.g. location the speed stability can be reduced to any desirable amount. This is not only important with regard to dynamic stability but also with regard to control input required for steady flight, gust response, etc.

IV. PILOT'S CONTROL INPUT FOR LEVEL FLIGHT

In steady level flight the horizontal component of the resultant aerodynamic force must be zero and the vertical component equal to the gross weight. In addition, the pilot has to tilt forward to such a degree that the sum of all pitching moments becomes zero. Or, in other words, the pilot's control moment must be equal to the total aerodynamic moment.

As shown in the previous paragraph, see also Figure 2, the aerodynamic moment depends to a large extent on the vertical c.g. location. For a low c.g. position the aerodynamic moments are high and an appreciable forward tilt of the pilot is required, and vice versa. Figure 3 shows the pilot's tilt β relative to the platform for a speed of 10 mph against the height of the c.g. It can easily be seen that for the lower range of the c.g. location the pilot would soon run out of control. The discussion of the next section shows that for the other extreme of very high c.g. positions (i.e. for conditions $M_u < 0$) a divergent aperiodic motion occurs. This means that two boundaries exist. For low c.g. positions the control moments are insufficient, for very high c.g. positions the ship becomes dynamically unstable.

Between these two extremes a certain range exists which gives about neutral dynamic stability and adequate control characteristics. For a flying platform, therefore, the vertical c.g. location has the same significance as the fore-aft c.g. location in a fixed wing aircraft.

V. GUST RESPONSE

A horizontal gust V_g produces a pitching moment

$$M_{gust} = M_u V_g \tag{10}$$

As the pilot cannot anticipate this disturbance, the initial angular acceleration in pitch (or roll) due to the gust is

$$\ddot{\alpha} = \frac{M_u V_g}{I} \tag{11}$$

where the quantity I denotes again the pitching (or rolling) moment of inertia of the platform including pilot. The curve of Figure 4 is based on the assumption that a gust of 10 mph strikes the platform in hovering flight. It shows that an increase in the height of the c.g. appreciably decreases the response to gusts. For $M_u = 0$ the platform does not pitch or roll at all. It should be noted that an increase in the height of the c.g. (for instance by raising the pilot) also considerably increases the moment of inertia, i.e., the curves of Figures 2 and 4 are not identical.

VI. DYNAMIC STABILITY (HOVERING)

In order to determine the effect of vertical c.g. location on the dynamic stability, numerical stability investigations for hovering flight have been conducted.* As for a linearized theory the vertical motion of the c.g. is independent of the longitudinal and lateral motion and no coupling exists between pitch and roll. the two degrees of freedom considered are:

1) horizontal linear velocity of the c.g.
2) angular displacement about the c.g.

With the exception of the damping in pitch (or roll) which was calculated, the stability derivatives are taken from truck tests. The resulting frequency equation is of the third order and generally has one real root and one pair of conjugate complex roots, i.e., the modes of motions are (a) an aperiodic motion and (b) an oscillation. See Figure 5. The curves of Figure 5 show the degree of stability of both modes against the vertical c.g. position. The full line refers to the oscillation and the dotted line to the aperiodic motion. For the condition $M_u = 0$ (zero speed stability) the oscillation splits up into two damped aperiodic motions and the original aperiodic motion becomes neutral. At c.g. positions below zero speed stability the aperiodic motion is damped and the oscillation undamped. An increase in the height of the c.g. up to the point of zero speed stability has the following effects:

a) the aperiodic motion becomes less stable
b) the oscillation becomes less unstable where the period of oscillation increases.

* Hiller ARD Report No. 112.1

As mentioned previously, for $M_u < 0$ (negative speed stability) the aperiodic motion becomes divergent; this range, therefore, must be avoided. Obviously, the most desirable c.g. location for low speed flight is the range just below $M_u = 0$ where both adequate control and stability characteristics can be obtained.

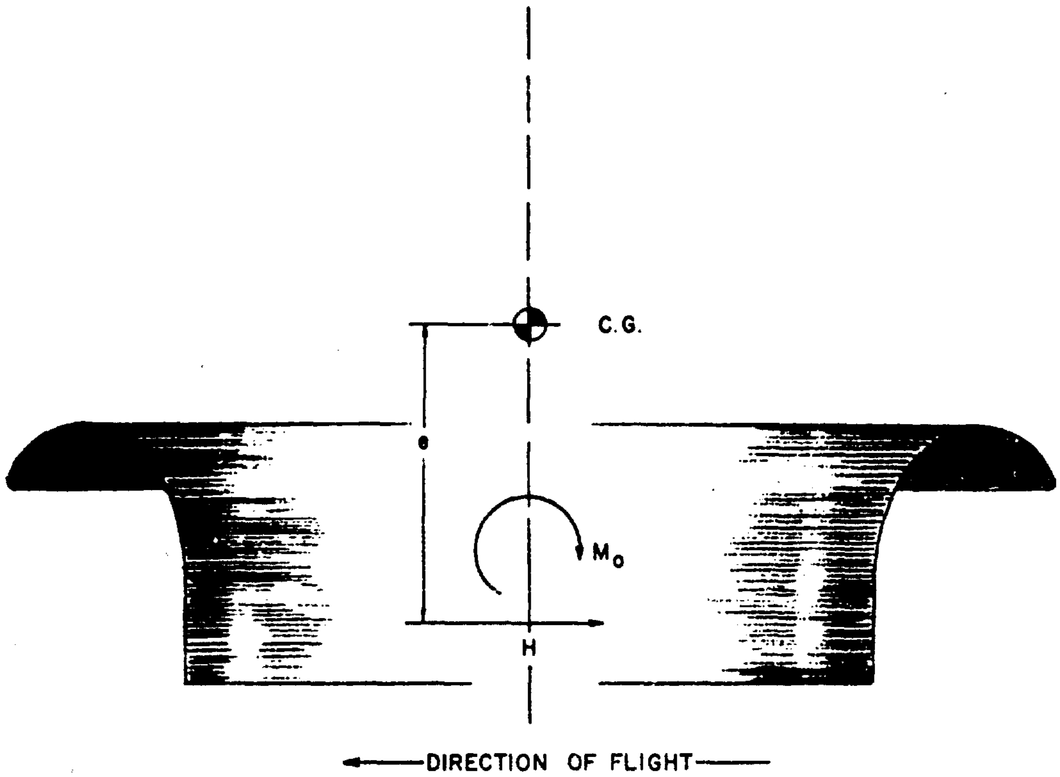

FIGURE 1: EFFECT OF LINEAR VELOCITY ON PITCHING OR ROLLING MOMENT

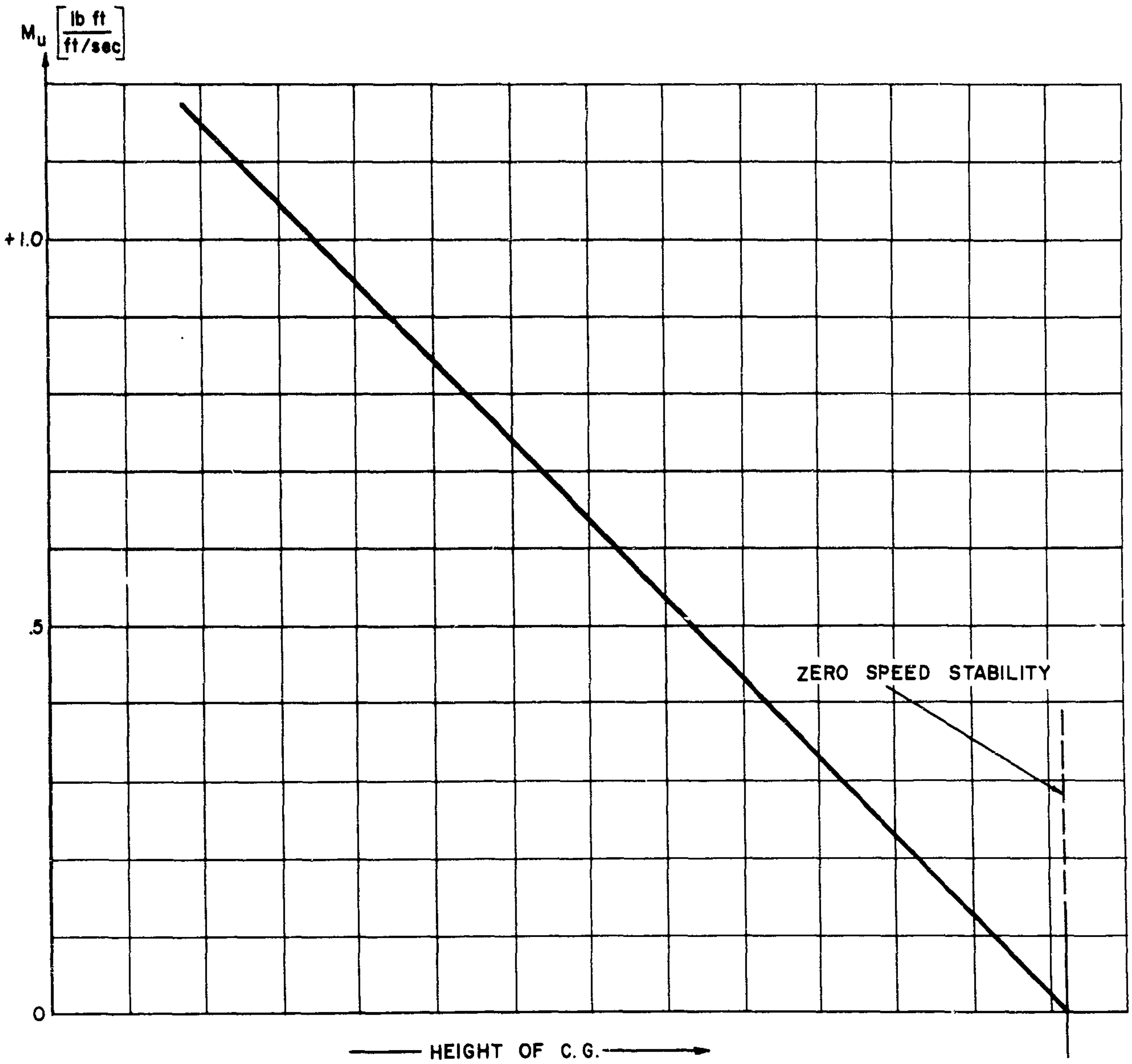

FIGURE 2: EFFECT OF C.G. LOCATION ON SPEED STABILITY

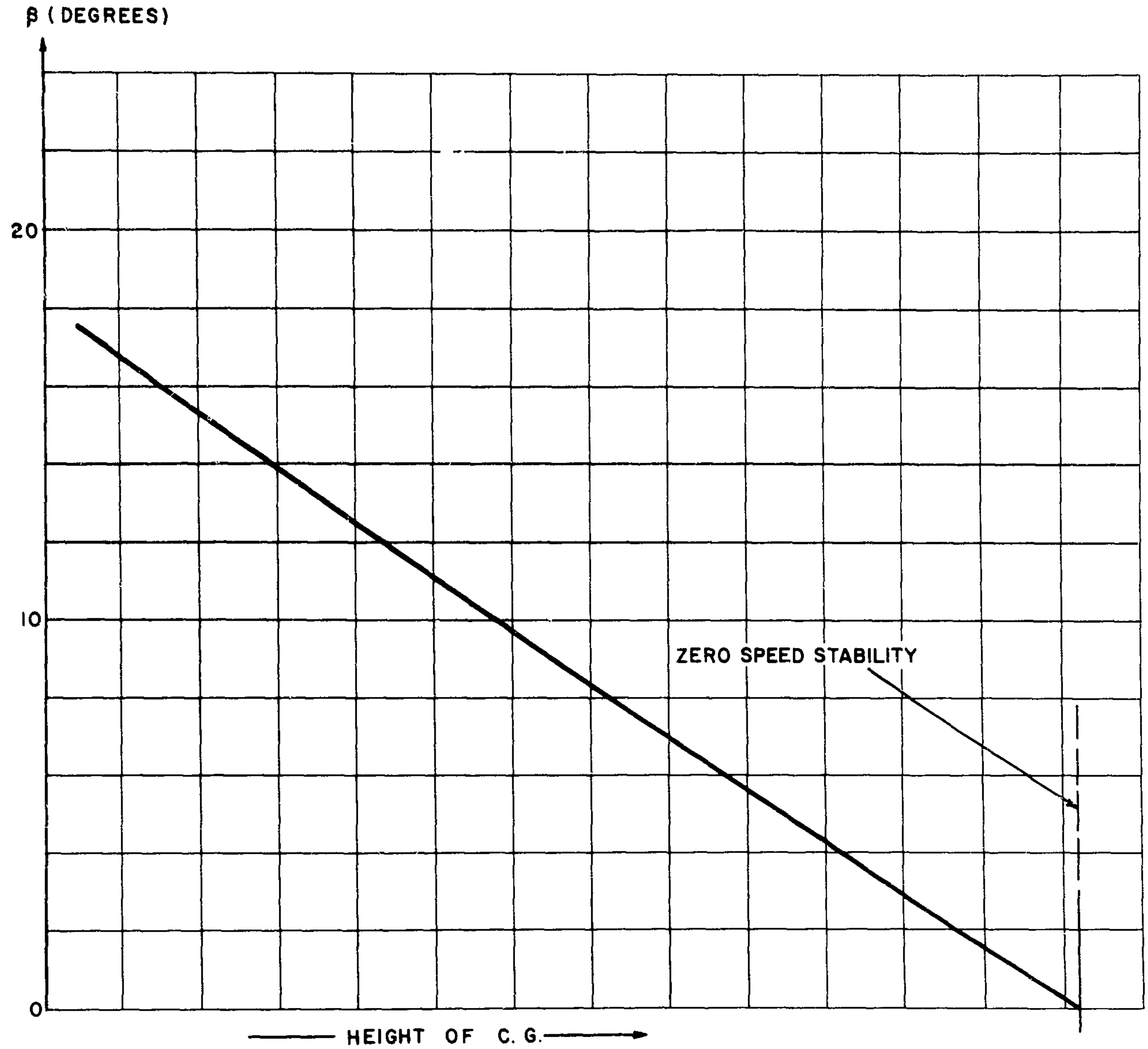

FIGURE 3: EFFECT OF C.G. LOCATION ON PILOTS TILT RELATIVE TO PLATFORM

10 MPH (PLATFORM TILT = 5°)

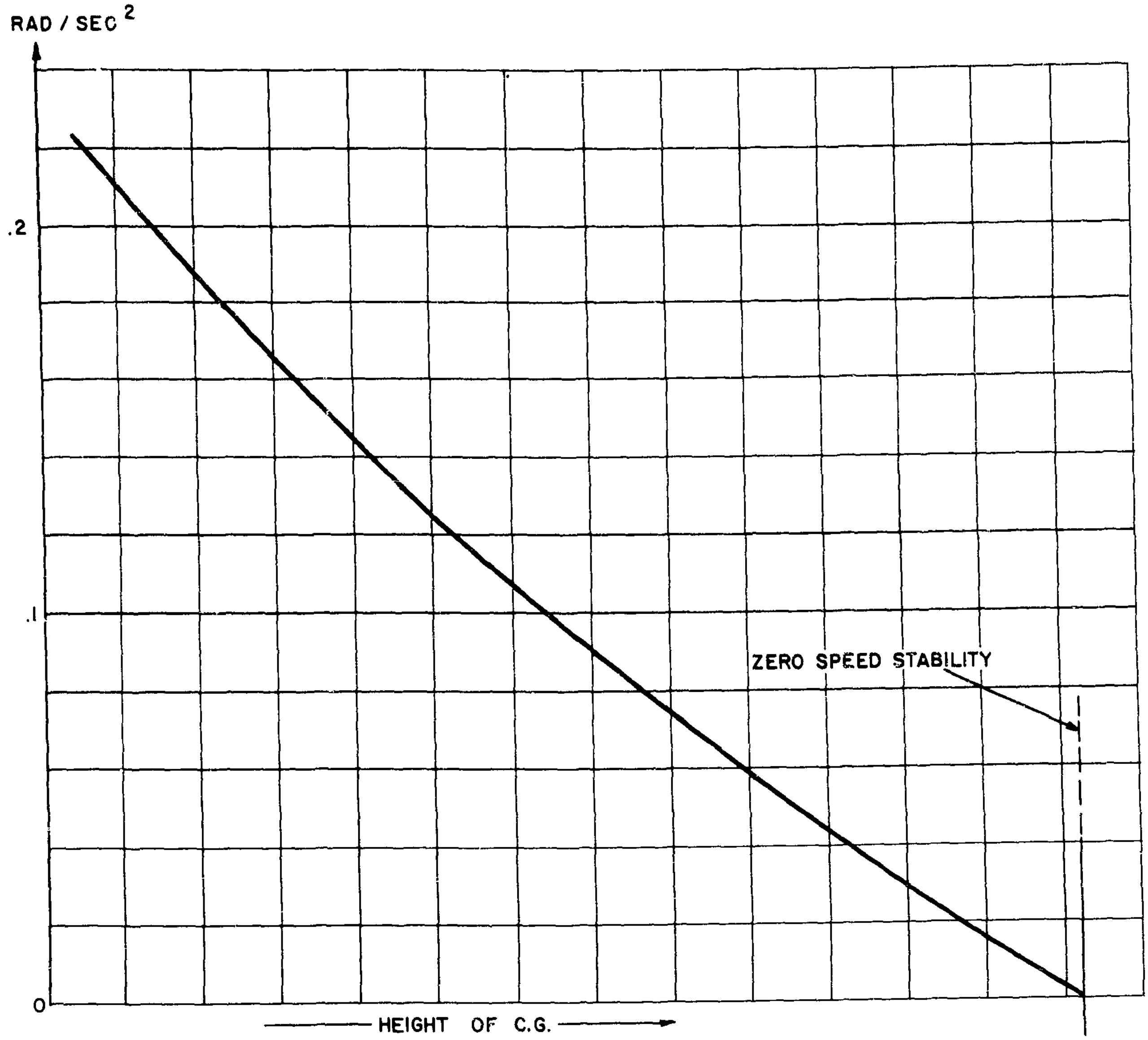

FIGURE 4: INITIAL ANGULAR ACCELERATION DUE TO A GUST OF 10 MPH

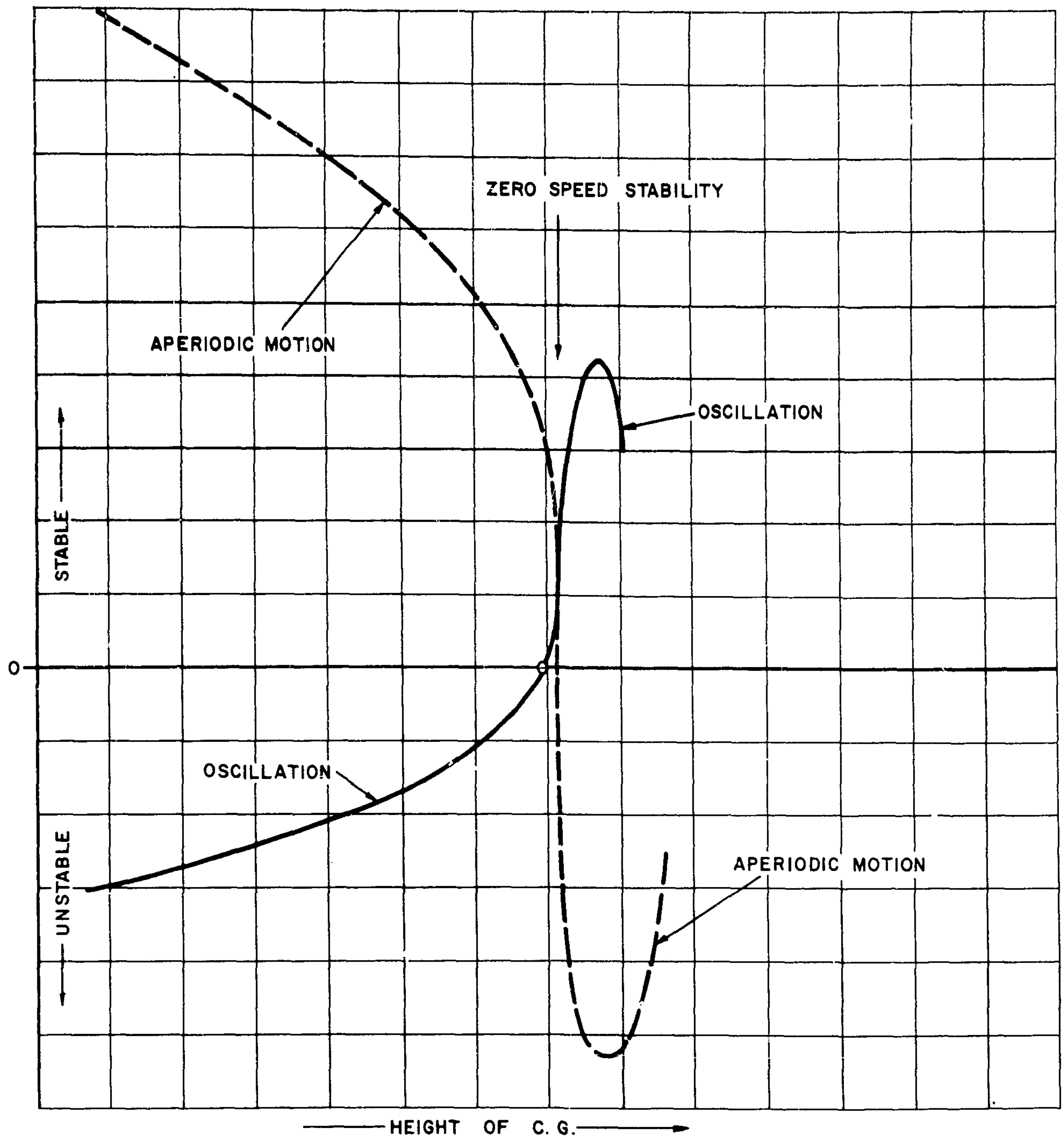

FIGURE 5 : EFFECT OF C.G. LOCATION ON DYNAMIC STABILITY